PREPARED IN COOPERATION WITH THE
AMERICAN SAMOA ENVIRONMENTAL PROTECTION AGENCY

Izuka, S.K., 1999, Hydrogeologic Interpretations from Available Ground-Water Data, Tutuila, American Samoa

INTRODUCTION

Tutuila is the largest (53 mi^2) and most populated (45,000 people in 1990 [U.S. Department of Commerce, Bureau of the Census, 1992]) island in the tropical South Pacific island group of American Samoa (fig. 1). Ground-water development on the island has grown from a few dug wells and scattered spring catchments prior to the 1960's (Davis, 1963) to more than a hundred drilled wells and about 9 Mgal/d of pumpage by the mid-1990's (Izuka, 1997).

In the 1970's, a ground-water data-collection network was established by a cooperative agreement between the U.S. Geological Survey (USGS) and the American Samoa Government through the American Samoa Environmental Protection Agency (ASEPA), American Samoa Power Authority (ASPA), and the Department of Public Works (DPW). This report describes hydrogeologic interpretations of the trends in selected records of pumpage, water level, and chloride concentration from wells on Tutuila and discusses the implications on the understanding of ground-water occurrence, response of the ground-water system to development, and the limitations to ground-water availability.

Source of data.--Pumpage, chloride concentration, and water-level data were collected by ASPA. Methods of data collection and processing are described in Izuka (1996, 1997). Rainfall data from Afono and Aasufou also were collected by ASPA. Rainfall data from the airport was obtained from the National Oceanographic and Atmospheric Administration, National Climatic Data Center (1997).

HYDROGEOLOGIC SETTING

Tutuila is a volcanic island elongated in the east-west direction (fig. 1). Except for the Tafuna-Leone Plain in the southwest part of the island, most of Tutuila is formed by steep, deeply eroded mountains that rise abruptly from the ocean to elevations as high as 2,142 ft. A discontinuous narrow coastal plain lies at the base of parts of the mountains. The Tafuna-Leone Plain, in contrast, is relatively low lying and has a gentler topography. Despite its name, however, the Tafuna-Leone Plain has many hills and more than 600 ft of relief.

The mountainous main part of Tutuila is composed of Pliocene- and Pleistocene-age alkalic igneous rocks, including thick lava flows and pyroclastic accumulations that are cross-cut by dense intrusive igneous rocks (Stearns, 1944; Macdonald, 1944, 1968). Sediments fill the valleys in the eroded mountains and form the narrow, discontinuous coastal plain adjacent to the mountains. Stearns (1944) divided the rocks of this region into several geologic units (table 1), but hydrologically, the rocks are similar in having relatively low bulk permeability (Davis, 1944). Bentley (1975) reported specific capacities ranging from 0.12 to 5.5 gal/min per foot of drawdown for wells in these rocks and sediments. In this report, all of the rocks and sediments of the older, mountainous part of Tutuila, are combined into one hydrogeologic unit called the "Older Volcanics" (table 1, fig. 2).

The rocks that form the Tafuna-Leone Plain are known as the Leone Volcanics (Stearns, 1944). These rocks are younger (Holocene age) than the Older Volcanics to the north (figs. 1, 2). The Leone Volcanics lie partly on the eroded flanks of the mountains formed by the Older Volcanics, and partly on marine sediments that overlie the offshore flanks of the Older Volcanics. The Leone Volcanics include thin lava flows, which form most of the flat area of the Tafuna-Leone Plain, and ash and cinder that form the hills on the plain. The fine ash in some cones has been weathered and consolidated to form tuff, whereas the coarser cinder of other cones has been only loosely consolidated (Stearns, 1944). The permeability of the Leone Volcanics is generally higher than the Older Volcanics, although locally, permeabilities are affected by the presence of low-permeability tuff and high-permeability cinder (Davis, 1963). Bentley (1975) reported specific capacities ranging from 3.1 to 187 gal/min per foot of drawdown for wells in the Leone Volcanics. In this report, the Leone Volcanics constitutes a second hydrogeologic unit distinct from the Older Volcanics (table 1, fig. 2).

RAINFALL

Ground water on Tutuila originates as rainfall. Rainfall on Tutuila varies with elevation above mean sea level, with an average of 211 in/yr at the rain gage in Aasufou (1,340 ft elevation), 158 in/yr at the rain gage in Afono (840 ft), and 125 in/yr at the gage in the lowlands near the airport (6 ft). Rainfall also varies seasonally, with higher rainfall from about October through April and lower rainfall from about March through September (fig. 3). Only a fraction of the rainfall recharges ground water, the rest either runs directly off the land surface into the ocean, is evaporated, or is consumed by plants. The proportion of rainfall that goes to ground water depends on several factors, including climate, geology, soil, vegetation, and land topography. This proportion has not yet been determined for Tutuila.

GROUND WATER

The water-table map in figure 4 shows the elevation of the surface of the saturated part of the Tutuila aquifer. Water-table elevations are high in the Older Volcanics that form the mountainous main part of Tutuila, and decline sharply toward the coast, centers of the valleys, and the Tafuna-Leone Plain. In contrast, the water-table in most of the Tafuna-Leone Plain is less than 20 ft and has a low gradient. Water levels are a few feet higher in the pyroclastic rocks compared to the rest of the Tafuna-Leone Plain.

As in other oceanic islands, fresh ground water on Tutuila is underlain by saltwater (fig. 5). The fresh ground water forms a lens-shaped body that is buoyed by the density difference between the saltwater (the saltwater has about the same salinity and density as ocean water) and freshwater. Because of this buoyancy, the height of the water table is related to the thickness of freshwater below sea level: the higher the water-table elevation above sea level, the greater the freshwater thickness below sea level. Application of this concept, known as the Ghyben-Herzberg principle, to the water-table elevations shown in figure 4 indicates that not only is the water level higher in the Older Volcanics than in the Leone Volcanics, but the thickness of fresh ground water below sea level is also greater (fig. 5).

The height and steepness of the water table and the thickness of fresh ground water vary with the distribution of recharge, location of discharge, rate of ground-water flow through the aquifer, and spatial distribution of aquifer permeability. Fresh ground water flows downward in inland parts of the aquifer, horizontally to the coast, then upward near the coast where ground water discharges (fig. 5). The water table in most island aquifers slopes toward the coastal discharge areas, but the steepness of the water-table slope is a function of aquifer permeability. In the low-permeability Older Volcanics, ground water saturates to the surface in many places and discharges to streams. The resulting water table in this part of Tutuila is steep (fig. 4 and 5). In contrast, in the high-permeability Leone Volcanics, the water table is lower and less steep than in the Older Volcanics. The slightly higher water levels in Iliili reflect the lower permeability of the ridge of pyroclastic cones compared with the highly permeable lava flows in other parts of the Tafuna-Leone Plain.

According to the Ghyben-Herzberg principle, the thickness of fresh ground water below sea level is about 40 times the elevation of the water table above sea level (h in fig. 5, inset). The principle assumes that the contact between freshwater and the underlying saltwater is a sharp boundary, but in reality, a diffuse transition zone exists where salinity grades from freshwater above to seawater below. The Ghyben-Herzberg principle is commonly used to estimate the vertical distance between the water table and a mixture of 50-percent freshwater and 50-percent seawater in the transition zone (fig. 5, inset). However, a 50-percent seawater/freshwater mixture has a chloride concentration of about 9,500 mg/L, which is much higher than the 250 mg/L maximum chloride concentration (equivalent to about 1.1 percent seawater) recommended for drinking water by the U.S. Environmental Protection Agency (1996). The thickness of freshwater may therefore be substantially less than the thickness estimated by the Ghyben-Herzberg principle. Application of the Ghyben-Herzberg principle to the water levels in figure 4 indicates that the fresh ground-water body would be several tens of thousands of feet thick in some places, but geophysical evidence indicates that ground water in mid-ocean volcanic islands is not likely to be present in significant quantities deeper than about 6,000 ft from the ground surface (Kauahikaua, 1993).

Effects of ground-water withdrawals and limitations on ground-water production.--In a pristine condition, flow in the fresh ground-water body is in a state of long-term average dynamic equilibrium. Seasonal variations may result in short-term imbalances, but in the long-term, average recharge rate is balanced by the average discharge rate.

When the natural balance of the fresh ground-water body is upset by artificial withdrawals such as well pumpage, the shape and size of the fresh ground-water body changes (fig. 6). Pumpage causes the fresh ground-water body to shrink by drawing down the water level in the well and the surrounding aquifer to form a cone of depression. Drawdown in the well increases as long as the cone of depression spreads, but the rate of increase of drawdown diminishes logarithmically with time (fig. 7). The logarithmic decrease in drawdown rate is sometimes misinterpreted as a stabilization of drawdown when in reality, drawdown is still increasing. The effects of the continually increasing drawdown may become apparent only after prolonged pumping (perhaps months or years). Pumping also induces saltwater to rise (in a process known as saltwater upconing because the rising saltwater forms a cone whose highest point directly underlies the well). With time, the drawdown and upconing spread over an increasingly larger area until they reach areas of natural ground-water discharge such as streams or the coast, and cause a reduction in the rate of ground-water discharge by an amount equal to the pumping rate. Well pumpage thus has the eventual effects of lowering the water table, raising the underlying saltwater, inducing landward encroachment of saltwater at the coast, and reducing streamflow and ocean discharge (fig. 6).

The yield of a well is constrained by the degree to which the changes brought about by these effects are considered acceptable. Excessive pumpage from a well can cause water levels to drop below the reach of the pump in that well or a nearby well. Excessive pumpage can also cause saltwater to contaminate a new or existing well, especially where the fresh ground-water body is thin or wells are drilled so deep that they are close to the freshwater-saltwater transition zone. Effects of pumpage on natural ground-water discharge to streams and the ocean may also have environmental consequences.

Construction of the water-table map.--The water-table map (fig. 4) was constructed on the basis of water-level data that were collected over several decades, including pre-pumping water levels in selected wells and elevations of springs and marshes (which represent the intersection of the water table and the ground surface). The data were compiled from the files at the USGS and ASPA, a topographic map of Tutuila (USGS, 1989), and information in Davis (1963) and Bentley (1975). The water-table map thus represents a view of the regional water table averaged over time. Short-term variations caused by ground-water development or seasonal variations in recharge may not be accurately represented, but these variations are probably localized and small relative to the scale of the water-table map.

The position and shape of the contour lines of the water-table map were interpolated between points of known water-level elevation. The interpolation assumes that the permeability within each hydrogeologic unit (fig. 5) is uniform, although small-scale permeability variations may exist. The water-table map also was drawn consistent with topography and streamflow characteristics. Stream-gage records and seepage measurements indicate that most of the streams in the mountainous part of Tutuila are perennial (Wong, 1996), probably as a result of ground-water discharge. The point where a stream becomes perennial represents the intersection of the stream with the water table. Wherever the stream is not perennial, the water table must be below the elevation of the stream bed. The water table cannot be higher than the land surface except where it emerges as a lake or pond. As a result, the contours of the water-table map bend into the stream valleys in the eroded mountains of Tutuila.

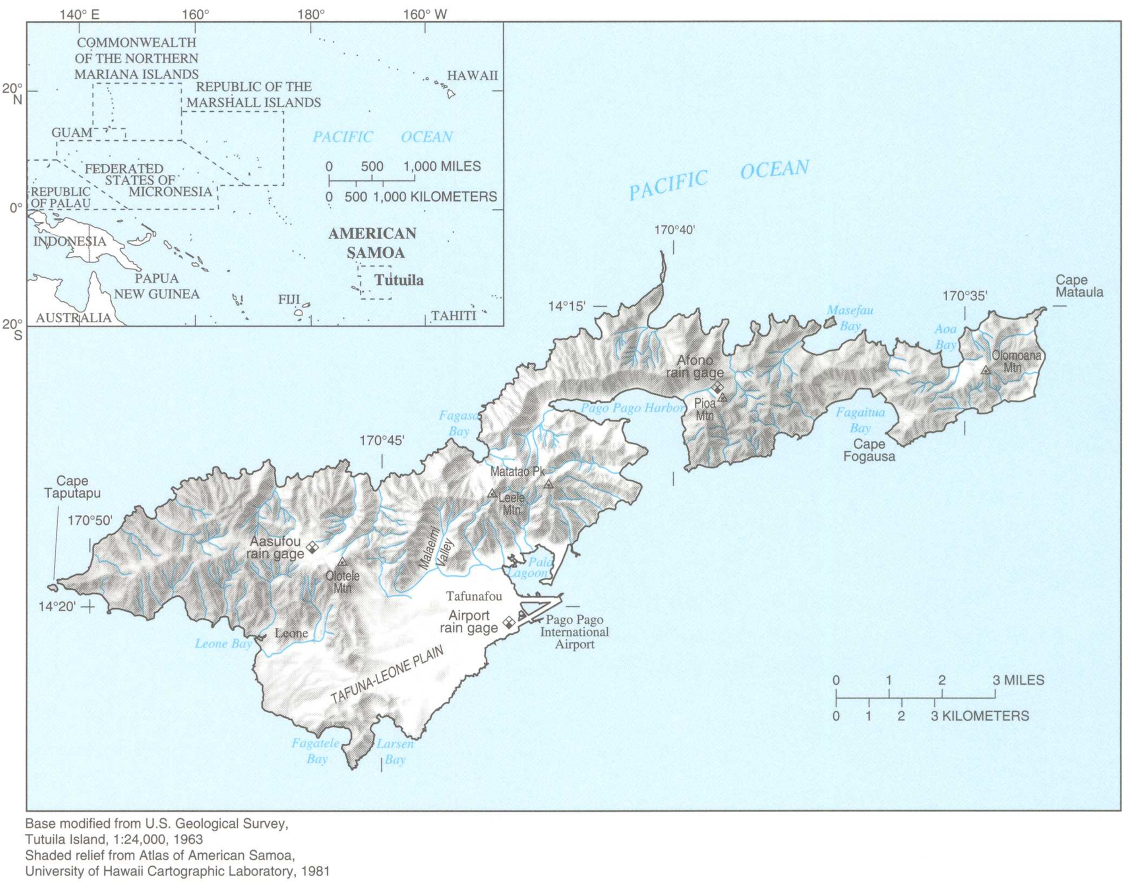

Figure 1. Tutuila, American Samoa.

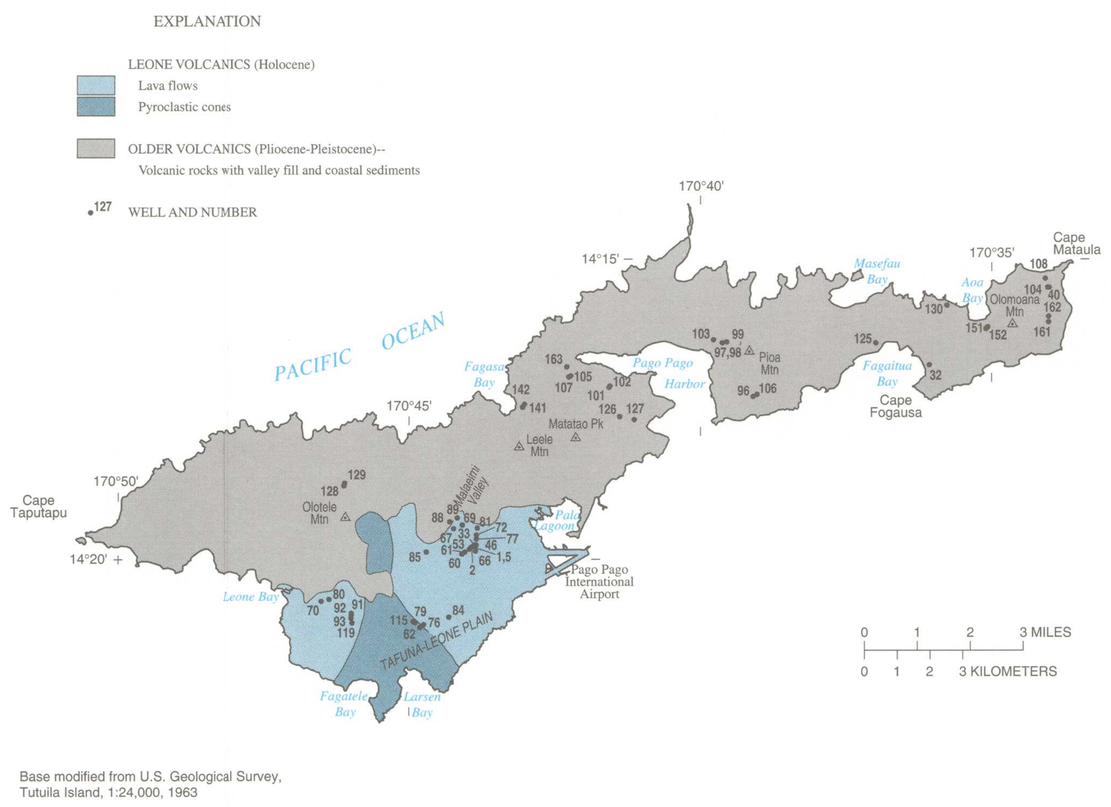

Figure 2. Hydrogeology of Tutuila, American Samoa. (Modified from Stearns, 1944, Davis, 1963, and Bentley, 1975).

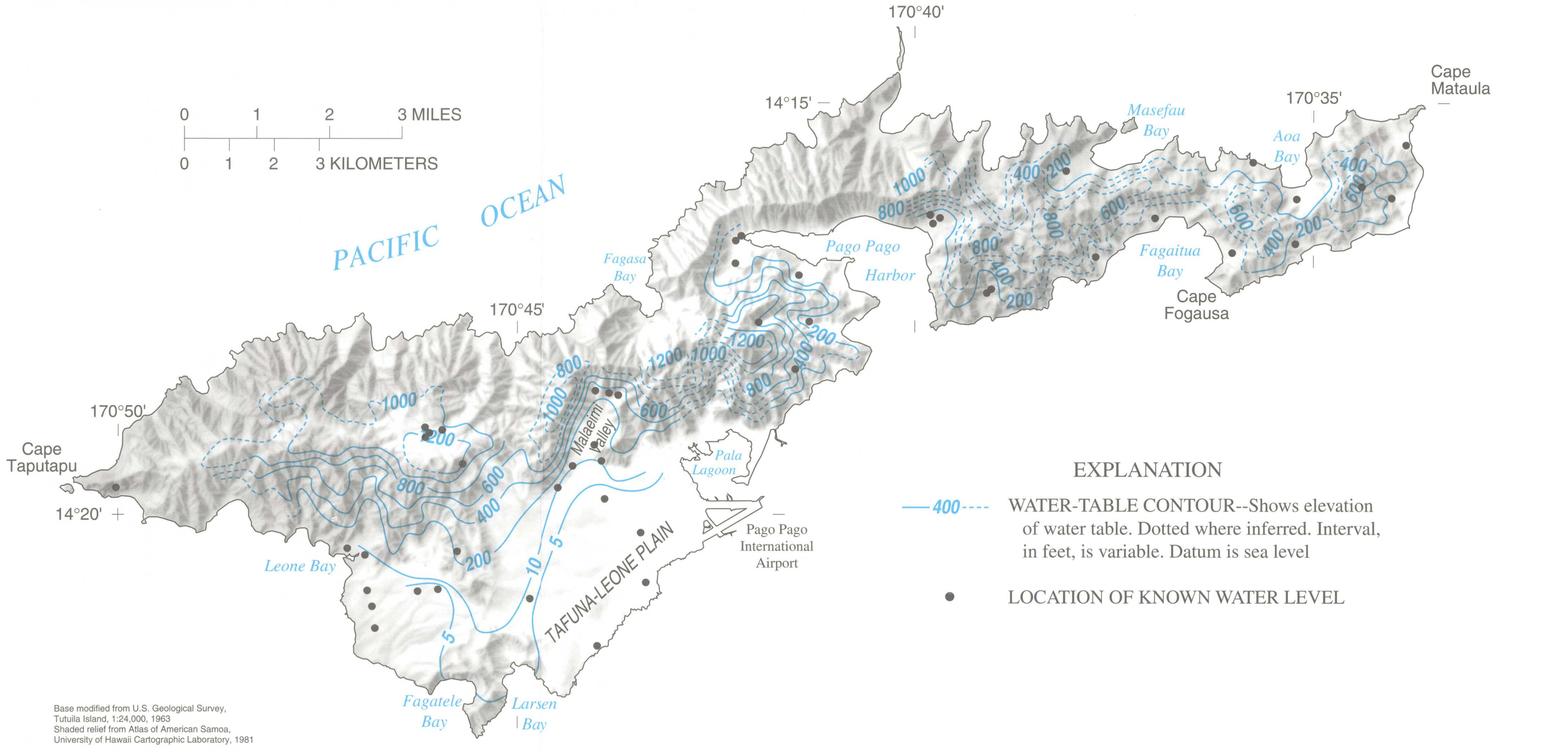

Figure 4. Water table on Tutuila, American Samoa. Compiled from information in Davis 1963, Bentley, 1975, and U.S. Geological Survey, 1989, and from data from the American Samoa Power Authority and files at the U.S. Geological Survey Hawaii District Office.

Table 1. Hydrogeologic unit names used in this report.

Hydrogeologic unit name used in this report	Description from Stearns (1944), Davis (1963), and Bentley (1975)	Correlative geologic units from Stearns (1944)
Leone Volcanics	Holocene-age lava flows and pyroclastic rocks of the Tafuna-Leone plain and upper Olotele Mountain. Relatively high permeability	Leone Volcanics
Older Volcanics	Pliocene- and Pleistocene-age volcanic rocks of the older, eroded, mountainous main part of Tutuila, and Pleistocene- to Holocene-age marine and terrigenous consolidated and unconsolidated sediments, including sediments that underlie the Leone Volcanics. Low permeability mostly, although reef rock underlying the Tafuna-Leone Plain may have higher permeability	Taputapu Volcanics Pago Volcanic Series Alofau Volcanics Olomoana Volcanics Masefau dike complex Trachyte plugs and dikes Sedimentary rocks

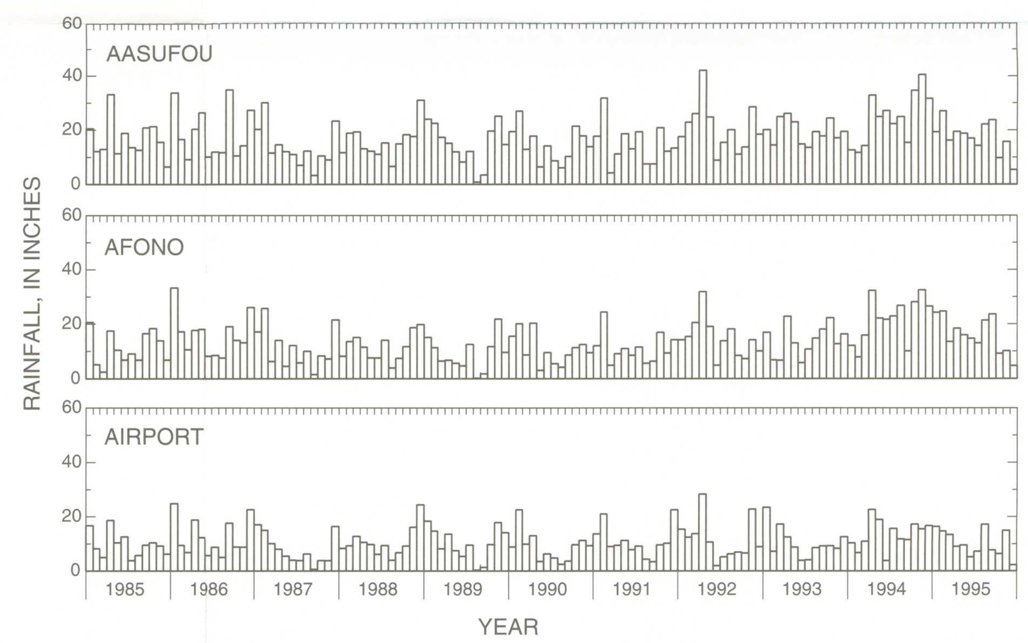

Figure 3. Rainfall at the Aasufou, Afono, and Airport gages, Tutuila, American Samoa. Data for the Aasufou and Afono gages from the American Samoa Power Authority; data for the airport gage from the National Oceanographic and Atmospheric Administration, National Climatic Center, 1997.

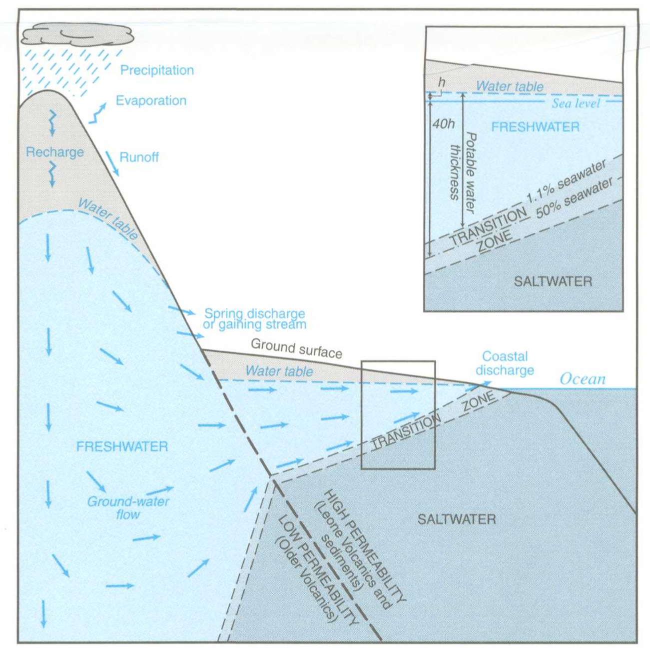

Figure 5. Schematic hydrogeologic section through part of Tutuila showing relations between water-table elevation, thickness of the fresh ground-water body, and transition-zone thickness.

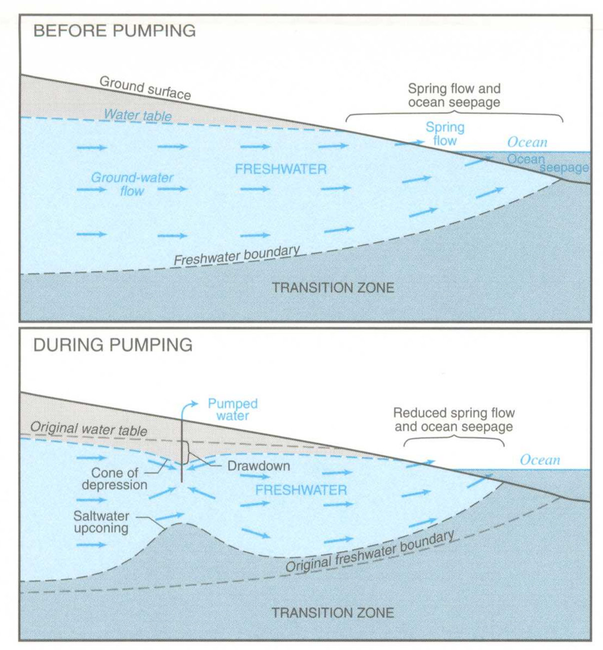

Figure 6. Effects of well pumpage on the fresh ground-water body in an island aquifer.

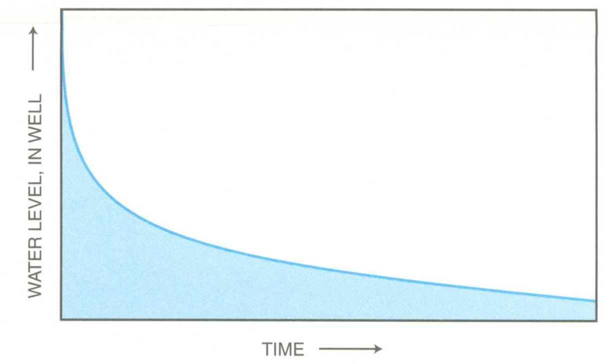

Figure 7. Theoretical time-drawdown curve for a pumping well.

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HYDROGEOLOGIC INTERPRETATIONS FROM AVAILABLE GROUND-WATER DATA, TUTUILA, AMERICAN SAMOA

by
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